DRISI

Caltrans Division of Research, Innovation and System Information

Research Results

Effect of Soil Slope on Lateral Capacity of Piles in Cohesive and Cohesionless Soils

Developing procedures for analyzing battered piles in deep foundations

Geotech/ Structures

MARCH 2013

Project Title:
Development of Reliable Methods to Analyze Battered Piles and Piles in Sloping Ground

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In collaboration with Oregon State University, Caltrans investigated the influence of slope proximity and batter on the lateral capacity of driven pile foundations.

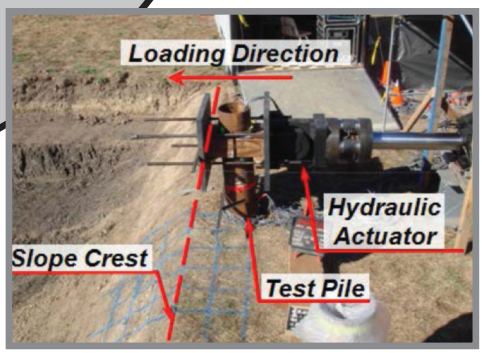
Task Manager:
Charles Sikorsky,
Senior Bridge Engineer
charles.sikorsky@dot.ca.gov

WHAT WAS THE NEED?

Highway bridge piers and abutments are usually supported on deep foundations using driven piles installed at an angle, or batter. Batter piles have an increased capacity to carry lateral loads compared to vertical piles of the same dimensions and materials. However, the procedure to analyze battered piles in these types of applications is very basic and represents a structural system approach that ignores the presence of soil. As a result, the design recommendations are too simplistic, leading designers to follow a conservative design approach that results in higher construction costs.

One of the most widely accepted methods for analysis and design of laterally loaded piles is the Winkler spring method in which the soil resistance along the pile is modeled using a series of nonlinear soil springs, commonly known as p-y curves. Most of the standard p-y curves in use are based on the results of full-scale lateral load tests on piles in level ground for a limited range of soil conditions and pile diameters.

Methods that have been recently developed to account for the effect of batter angle and soil slope are generally based on results from analytical solutions and, in the case of cohesionless soils, limited centrifuge test results. Some of the recommendations have been implemented in current design practice but have yet to be validated with full-scale test results. The available recommendations for cohesive soil slopes are based on analytical solutions and only account for the lateral capacity of short piles. Thus, what is needed is a procedure for the design of battered piles or piles in sloping ground based on results from full-scale tests in both soil conditions.



Test setup

WHAT WAS OUR GOAL?

The goal was to analyze the effects of soil slope on the lateral capacity of piles in cohesive and cohesionless soils to improve design guidance for deep foundations.

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Caltrans improves mobility across California by performing applied research, developing innovations, and implementing solutions.

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WHAT DID WE DO?

Two series of full-scale lateral load tests were conducted in cohesive soils and cohesionless soils. A reliable and usable method to predict the lateral force capacity for piles with batter angle and soil slope effect was developed. The study included a series of full-scale lateral loading tests under static loading for two baseline piles. For testing purposes, piles were installed on the crest (0D) and at various pile diameters (2D, 4D, and 8D) from the slope crest, and one pile was installed on the slope. A total of 18 full-scale tests were conducted. For consistency of the test results and to accurately evaluate the effects of soil slope, variations of other factors, such as pile and soil properties, were kept at a minimum.

WHAT WAS THE OUTCOME?

Based on the experimental and analytical results, the main findings on lateral capacity of piles in cohesive soils are:

- For small soil displacements (less than 0.5 inches), the proximity of slope has an insignificant effect on the lateral pile response. At larger soil displacements, the proximity of slope adversely affects the lateral capacity of piles and consequently the back-calculated p-y curves.
- For maximum allowable pile deflection of 0.25 inches under Service Limit State Load, as mandated in article 4.5.6.5.1 of the Caltrans Bridge Design Specifications (BDS), the slope appears to have an insignificant effect for piles located 2D or more from the slope crest.
- For piles installed on the slope crest, the effect of slope should always be considered at all displacement levels.
- The effect of slope on the lateral capacity was insignificant for piles installed at distances of 8D or greater from the slope crest.

The main findings for cohesionless soils are:

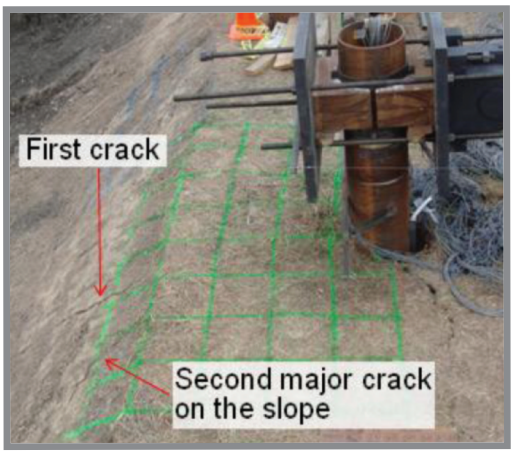
- The effects of slope on lateral pile capacity are insignificant at displacements of less than 2 inches for piles located 2D and greater from the crest.
- For piles located at 4D or greater from the slope crest, the effect of slope is insignificant for the analyzed ranges of soil displacements on p-y curves.
- For all testing cases, the lateral capacity was significantly higher than the 5 kips noted in the Caltrans BDS for 12-inch steel pipe piles for maximum allowable pile deflection of 0.25 inches under Service Limit State Load.

WHAT IS THE BENEFIT?

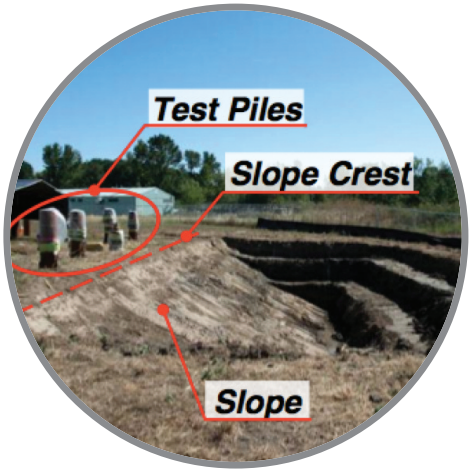
Current analysis methods typically overestimate the effects of slope on lateral pile capacities, often resulting in over-compensating the design and costing more to build. This research showed that the influence of slope proximity is minimal approximately two pile diameters away from the slope. In addition, the proximity of the slope is negligible at small pile displacements. As a result, improved design guidance material will reduce the required number of piles in a foundation near a slope, reducing construction costs.

LEARN MORE

To view the full report:
www.dot.ca.gov/hq/esc/earthquake_engineering/Research_Reports/vendor/uc_san_diego/2012-03/Final%20Report%20CA11-0932%2059A0645.pdf



Crack pattern at 6-inch pile top displacement



Overall view of the completed slope excavation